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journal or publication title	IEEE Micro Electro Mechanical Systems, 1995, MEMS '95, Proceedings
volume	1995
page range	145-150
year	1995
URL	http://hdl.handle.net/10097/46389

Development of a microphotocantilever for near-field scanning optical microscopy

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Abstract

A new type of near-field scanning optical microscopy (NSOM) using a micro-cantilever with a photo diode on its tip is described. The photo-sensitive cantilever, called a microphotocantilever, was fabricated using micromachining techniques and its use demonstrated. Fine NSOM images below 20 nm are obtained. Atomic force microscopy (AFM) can be done simultaneously to NSOM using the microphotocantilever. Well correlated NSOM and AFM images are obtained in the near-field optical mode.

Introduction

Near-field scanning optical microscopy (NSOM) is a very promising technique because it allows high resolution imaging beyond the optical diffraction limit while maintaining compatibility with many techniques used in conventional optical microscopy.

Much of the research into NSOM has been done using an arrangement that has a narrow aperture at the apex of a pointed transparent tip coated with an opaque metal film[1-5]. Light that passes through both the aperture and the object in a forward direction is detected. The resolution capability of this type of NSOM has been demonstrated in the 20 to 50 nm range. However, the aperture probe is not easy to prepare, and it is also difficult to maintain a fixed distance from the tip to the sample during scanning.

A more recent type of NSOM is based on the tapping of an evanescent wave by an uncoated transparent tip[6-10]. The operating principle is analogous to that of an electron scanning tunneling microscope. Because it has no aperture, the probe of this NSOM is easy to prepare but the resolution is less well defined than that of NSOM through an aperture.

Two things are needed to make a NSOM system easier to use and to extend its applicability to samples of arbitrary topography. The first is a distance-regulating mechanism capable of automating the initial approach and maintaining the tip at a fixed distance from the sample over the entire course of a scan. The second is a method of mass- fabricating uniform and high-quality tips. With few exceptions, NSOM

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researchers use sharpened optical fibers or pulled glass pipettes as tips.

A new type of NSOM that meets both of these needs by using a micro-cantilever with a photo diode on its tip is described. The photosensitive cantilever, which we refer to as a microphotocantilever, was fabricated using micromachining techniques and has been successfully demonstrated. Fine NSOM images below 20 nm were successfully obtained.

Concept

The concept of a new NSOM is shown in Fig 1. An evanescent wave is generated on a glass substrate by total internal reflection of a 2-mW HeNe laser beam focused to about 500 μm. The sample is especially designed to accommodate a laser beam at an angle so that the light is totally internally reflected. Even though no real part of the light escapes into the air, an optical evanescent field extends into space. When the tip is brought into close proximity of the sample, it disturbs the evanescent field causing light to be scattered. The scattered light can then be collected by the photodiode at the tip. A distance regulating mechanism automates the initial approach and maintains the tip at a fixed distance from the sample during a scan. This mechanism is based on measuring the deflection of the cantilever by using an AFM laser and a two-segmented photodiode. Accordingly, AFM imaging can be done simultaneously to NSOM imaging.

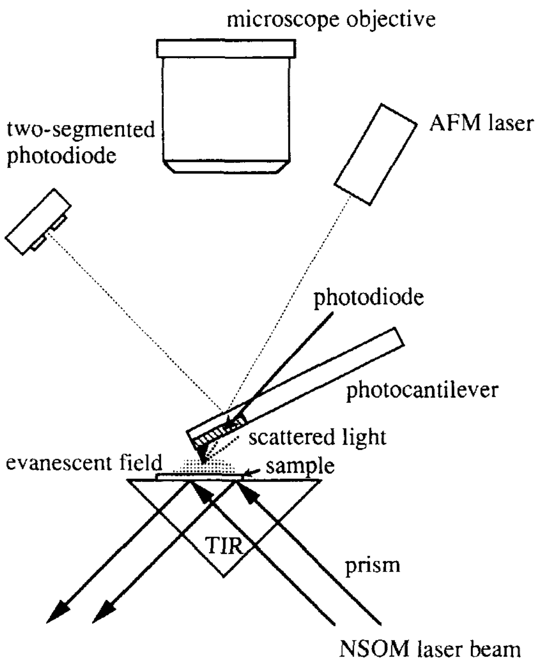

Fig. 1 Concept of the new NSOM.

Fabrication of the photocantilever

Figure 2 shows a silicon photocantilever structure with a photodiode. The photodiode detects non-propagating optical evanescent fields extending above the surface of a glass prism illuminated at an angle of total internal reflection.

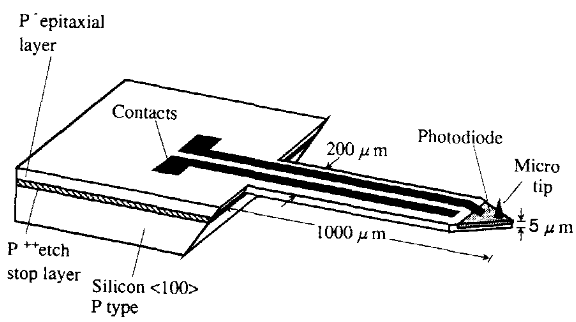

Fig. 2 Perspective view of the photo-cantilever.

Figure 3 shows the fabrication process of the photocantilever. A boron-dope etch-stop layer ($Na=3x10^{20}$) is formed on a p-type Si 4-inch-diameter wafer substrate (5-10 Ω-cm). Then, a 5-μm thick epitaxial p-layer ($Na=1x10^{14}$) is grown on the etch-stop layer. The photodiode is formed by P-ion implantation ($Na=7x10^{13}$) with 100-keV energy. The cantilever is patterned using reactive radio-frequency dry etching. A thick high-temperature polyimide baked at 400 degree C is formed on the front of the substrate to protect the photo device during etching the back of the substrate. Finally, the cantilever is shaped by etching the substrate using ethylene diamine pyrocatechol (EDP). The cantilever has both a low force constant (on the order of 1 N/m) and a high resonant frequency (usually greater than 10 KHz).

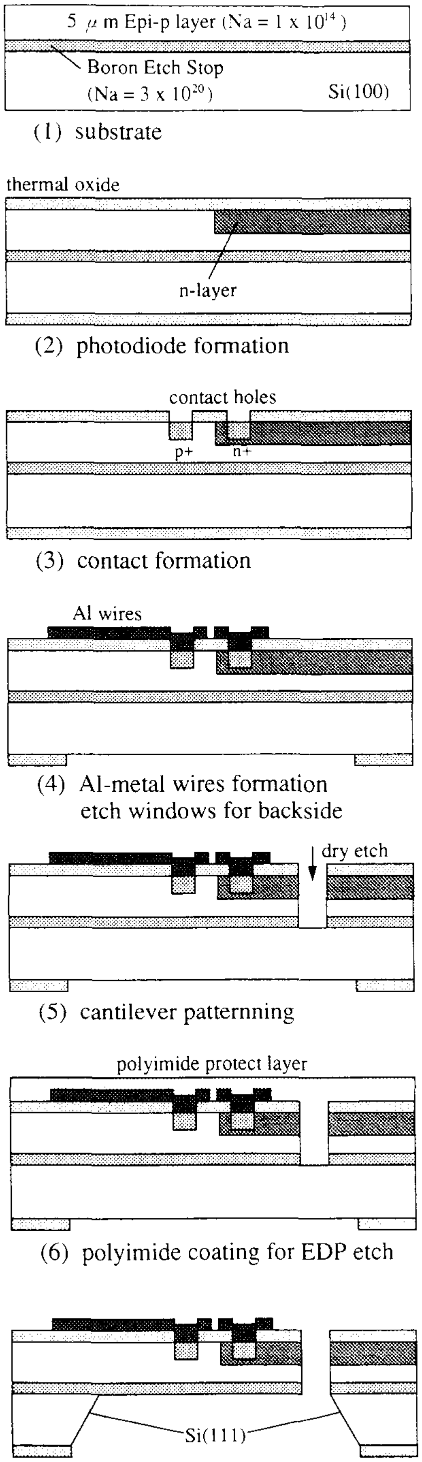

Fig. 3 Fabrication process of the microphotocantilever

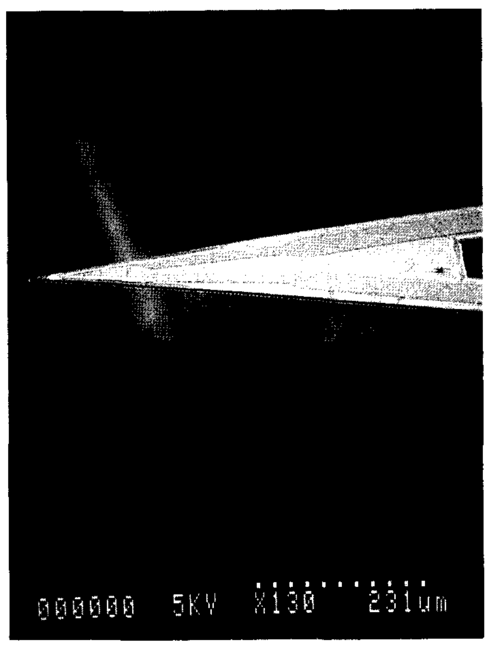

Fig. 4 SEM image of the photocantilever tip.

Results and Discussions

Figure 4 shows a scanning electron microscope photograph of the end of a photocantilever. In the AFM mode, the cantilever's deflection is measured using an optical beam deflection technique. To measure near-field optical sensitivity, the output of the photodiode was measured while the spacing between the cantilever and the sample was modulated. The resulting optical signal power versus distance curve is shown in Fig. 5. The vertical axis is optical signal power (2.5 nW/div.) and the horizontal axis represents the separation between the tip and the sample (350 nm/div.). Starting at the lower left corner, the optical signal level is zero when the tip is very far from the sample. At the right of the graph, the curve rises sharply from the noise floor to a saturated value of 27.5 nW. As the tip is retracted from the surface, meniscus forces from the contamination layer on the surface hold the tip to the surface until the cantilever bends sufficiently to cause the tip to snap away from the sample, this is shown in the upper left of the graph. The decay length of the curve is approximately 200 nm which corresponds well with previously published results.

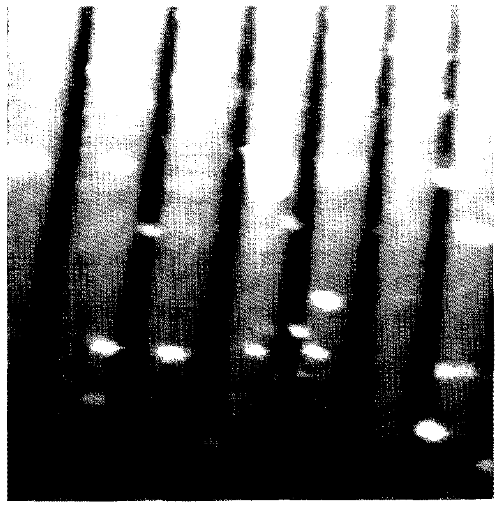

Fig. 6 (a) AFM image of a CD disk grating. The area is 10 μm x 10 μm .

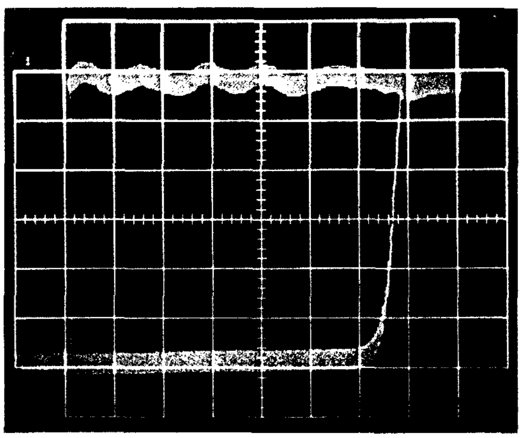

Fig. 5 Optical signal versus distance curve.

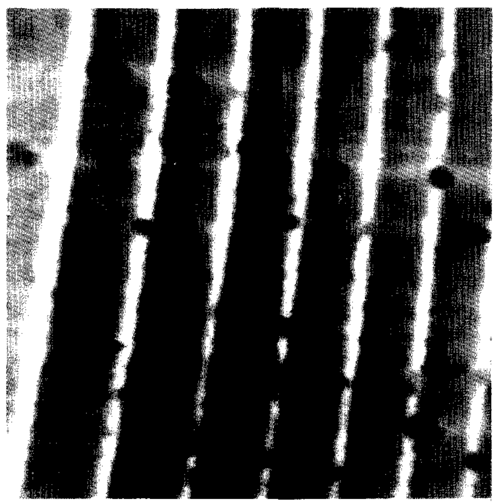

Fig. 6 (b) The corresponding NSOM image.

The photocantilever was used in both the AFM and the NSOM mode to image a compact disk grating. Figure 6(a) is an AFM image of a 1.6-μm period grating and the corresponding NSOM image is shown in Fig. 6(b). The step height of the grating is approximately 180 nm. The AFM and NSOM images correspond well. Note the identical location particles which are evident in both images. Figure 6(c) is a magnification of Fig. 6(c). The smallest feature we have resolved by NSOM is below 20 nm.

Fig. 6 (c) The magnification of (b).

Figure 7 is an NSOM image of dried chromatophore film that is 2-3 nm thick. Overlap of the very thin chromatophore film is observed.

Fig. 7 NSOM image of dried chromatophore film. The area is 3 μm x 3 μm .

Conclusion

A new type of NSOM using a microphotocantilever with a photo-diode on its tip is described. This NSOM is capable of simultaneous imaging. This NSOM detects scattering light with its tip very efficiently. The micromachining fabrication process is simple and appropriate for mass production. Fine NSOM images below 20 nm were obtained.

Acknowledgements

We wish to thank N. Kakuta for micromachining the device, and Y. Tanaka for preparing the setup.

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